Insect Science (2010) 17, 21–28, DOI 10.1111/j.1744-7917.2009.01284.x

Efficacy of an esfenvalerate plus methoprene aerosol for the control of eggs and fifth instars of *Plodia interpunctella* (Lepidoptera: Pyralidae)

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Abstract Aerosol insecticides may provide an alternative to fumigants for control of the Indianmeal moth, *Plodia interpunctella* (Hübner), the Indianmeal moth, a major insect pest of stored processed food. In this study, eggs and larvae (5th instars) of *P. interpunctella* were exposed to aerosol applications of the pyrethroid esfenvalerate and insect growth regulator methoprene, alone and in combination, in open and obstructed positions inside small sheds. When larvae were exposed to methoprene alone, adult emergence from those exposed larvae was 7.1% ± 1.5%. In contrast, adult emergence was 92.5% ± 3.5% when larvae were exposed to esfenvalerate alone. When eggs were exposed to methoprene, adult emergence of those exposed eggs was approximately 75%; however, when eggs were exposed to esfenvalerate, adult emergence was approximately 35%. In the combination treatment of methoprene plus esfenvalerate at their respective label rates, adult emergence following larval exposure was 0.91% ± 0.61% compared to 16.3% ± 9.6% when eggs were exposed. Based on our results, methoprene alone is highly effective in reducing adult emergence after larval exposure. However, it is not as effective on eggs as esfenvalerate. A combination treatment of esfenvalerate plus methoprene could be used to control eggs and the wandering-phase larval stages of *P. interpunctella*. An economic risk analysis also supports a strategy of combining methoprene and esfenvalerate.

Key words control, Indianmeal moth, *Plodia interpunctella*

Introduction

The Indianmeal moth, *Plodia interpunctella* Hübner, is a pyralid moth that can be present in various phases of the food manufacturing and distribution channel (Doud & Phillips, 2000; Johnson *et al*., 2003). *Plodia interpunctella* is a cosmopolitan insect pest that can infest different grains, dried fruit and nut products (Mohandass *et al*., 2007). Infestations can lead to equipment damage, physical product losses, aesthetic damage and unpleasant odors. Negative consumer feedback and experiences associated with infestations of *P. interpunctella* can also affect the manufacturing and distribution process of packaged food products.

Eggs and the wandering-phase 5th instars are vulnerable stages that could be exposed to aerosol insecticides applied inside a structural storage facility. Unlike fumigants, aerosols do not penetrate packaging materials; therefore treatment needs to be made when *P. interpunctella* is on the exterior of a package. Eggs oviposited in unconcealed areas may come into contact with residues from the deposition of an aerosol application of insecticide, while wandering-phase larvae would contact the insecticide when they leave the food source to find a pupation site. The wandering-phase larva of *P. interpunctella* is generally difficult to control with conventional neurotoxic insecticides compared to adult stored-product beetles (Arthur, 1995, 1997).

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Eggs of stored grain and fruit pests are often the most difficult life stage to kill with fumigants (Weller & Morton, 2001; Armstrong & Whitehand, 2005). One possible control strategy for *P. interpunctella* is to combine the pyrethroid esfenvalerate in combination with methoprene, an insect growth regulator (IGR) that is a juvenile hormone analogue. Pyrethroids are effective as immediate contact insecticides, whereas methoprene provides residual control.

One constraint on integrated pest managers for controlling *P. interpunctella* inside storage facilities is the cost associated with insecticides, applicator labor and/or equipment, and also costs associated with shutdown/loss of production. Economic analysis of methyl bromide alternatives using enterprise budgets for specific field crops have been developed (Nelson, 1996; Byrd *et al*., 2006). However, similar studies are not usually done when evaluating insecticides for control of *P. interpunctella*. Therefore, the objectives of this study were to: (i) determine the effect of aerosol applications of methoprene alone and in combination with esfenvalerate aerosol on adult emergence after exposure of eggs and larvae of *P. interpunctella*; and (ii) estimate differences in cost and risk associated with different application rates.

Materials and methods

General procedures

The *P. interpunctella* used in the experiments derive from a laboratory colony established in 1988 and periodically supplemented with wild individuals from collections in Riley County, KS, USA. The colony is located at the USDA-ARS Grain Marketing and Production Research Center in Manhattan, KS, USA, and has been maintained continually in environmental growth chambers (Forma-Scientific, Thermo Electron Corporation, Waltham, MA, USA) at 27 ± 1°C, approximately 40% RH, and in constant darkness except for when the incubator was opened. Relative humidity was maintained using pans of water (no salt added) in the bottom of the incubator. Larvae have been reared on a standard enriched wheat diet consisting of cracked wheat and wheat shorts (4.4 kg), brewer's yeast (22 g), sorbic and benzoic acid (9.5 g each), honey (240 mL), glycerin (240 mL) and water (120 mL). Voucher specimens from this colony have been deposited in the Kansas State University Museum of Entomological and Prairie Arthropod Research under Lot Number 208.

During experiments insects were placed on a clean diet following treatment and allowed to develop and/or mature to the adult stage under the environmental conditions described above. Three separate experiments were conducted using five small wooden sheds that were constructed in 1996. Three of the sheds were 2.8 m wide × 5.9 m long × 2.0 m high and two of the sheds were 2.8 m wide × 5.9 m long × 2.2 m high. A false floor was constructed in the shed using drywall, which was then painted, and the walls and roof of the sheds were lined with plastic. The construction of the interior of the sheds was described in detail by Toews *et al*. (2005a, b).

In each shed, concealed conditions such as those that could be found in a food storage warehouse were created using four corrugated cardboard boxes measuring 0.46 m × 0.46 m × 0.6 m placed over wooden pallets measuring 1.2 m × 1.0 m that were suspended on concrete blocks. Concrete blocks were used to raise the pallets so that treatment arenas, which will be described below, could be placed underneath the pallets. Adult moths were set up in individual colony jars, and the next day eggs were collected from these jars to use in the test, hence the eggs were less than 24 h old. These eggs were exposed to the aerosol spray in 100-mm Petri dishes painted with acrylic paint to reduce static. Actively wandering 5th instars were exposed using a series (five sizes) of cardboard garment boxes nestled together and secured with a mixture of instant tapioca and water, to hold the boxes together. Boxes were then taped with painter's tape around the bottom edges so that larvae could not escape the aerosol by crawling under the boxes. Box dimensions ranged from 21.9–53.3 cm long and 21.6–35.6 cm wide; when stacked inside each other, the distance from each side was approximately 2.54 cm from the next closest box edge (Fig. 1). The glue mixture was previously determined to have no adverse affect on the larvae. This arrangement of boxes was designed to contain the wandering larvae during the 2-h exposure period, which was time of exposure as specified by the insecticide labels for both products used in the study. Preliminary experiments were conducted to determine that the box arrangement would contain the larvae during the 2-h exposure period. Within each shed, positions were designated as unobstructed, which were on the floor of the shed, and concealed, which were underneath the pallet. The standard experimental set-up of each shed is illustrated in Fig. 2. Unobstructed positions were expected to be fully exposed to the settling aerosol particles, and concealed positions were expected to be potentially shielded from the settling particles.

Experiment 1

Applications were done using a hand-held ultra low volume (ULV) applicator (model no. E2 MLD® Chemical

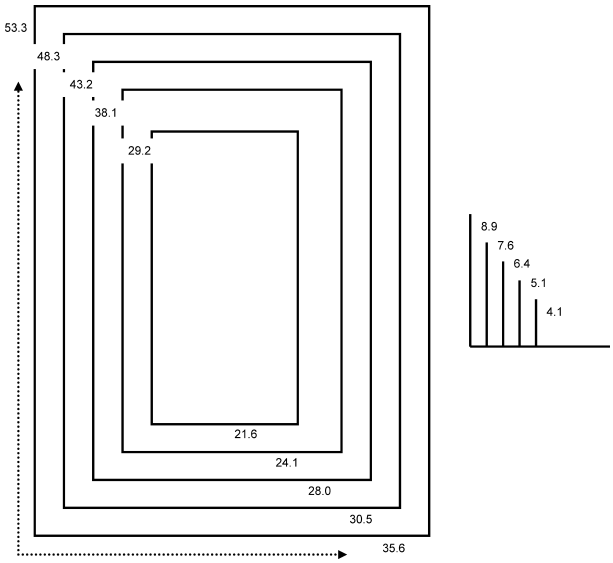

Fig. 1 Experimental arenas used contain wandering-phase larvae of *P. interpunctella* (drawing not to scale). Construction of these arenas is described in detail in the Materials and methods section. Numbers in this figure represent length and width of the individual boxes, in cm.

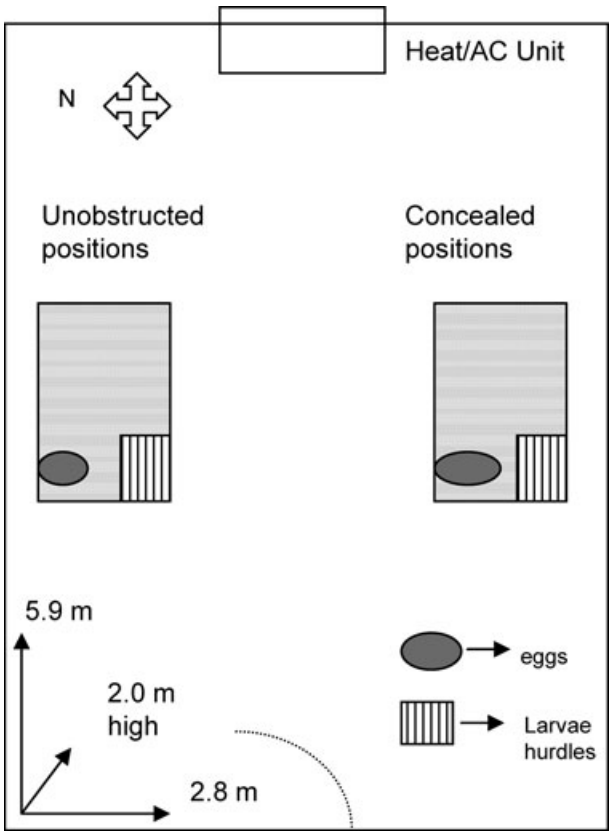

Fig. 2 Set-up and arrangement of the pilot-scale sheds for Experiments 1, 2 and 3. Concealed positions were created by making a mock pallet, as described in the Materials and methods section. Position of the entry door is marked with the dashed gray curve and open and concealed positions are labeled (drawings not to scale).

Dispersal Unit, MicroGen Equipment Corporation, San Antonio, TX, USA). Each of four sheds was treated with methoprene IGR aerosol based on the label rate of 3 mL of the Diacon II® formulation (300 mg active ingredient [AI]/mL, Central Sciences International, Dallas, TX, USA), per a space volume of 280 m^3). The insecticide was prepared by mixing 1.9 mL methoprene with 200 mL of the petroleum-based carrier Isopar-M. The target volume for application in two of the smaller three sheds was 35.7 mL diluted solution and 40.0 mL for the larger two sheds. The remaining small shed was untreated and served as a control. This corresponds to the label rate for aerosol applications, and the equipment dispenses aerosol at the rate of 29.5 mL per 60 s. The insecticide was applied by dispensing it from the applicator for the time calculated to achieve the label rate for the two shed sizes. The person applying the aerosol stood approximately 3 m from the doorway (Fig. 2) with the door closed, pointed the nozzle toward the back of the shed, and slowly pivoted during the spray to attempt an even dispersal of the aerosol. Timing of the spray was done by the applicator and also a person outside the treatment area. Solutions were weighed prior to and after application to ensure that the target amount of chemical ([AI]/m^3) was applied to each shed.

The experiment was conducted as two separate blocks (different times), with four replicates of each block. Eggs and fifth instars were placed in unobstructed and concealed positions with three sub-replicates of each. In this experiment, twenty 100-mm Petri dishes lined with filter paper containing 20 eggs each were placed in the treatment areas immediately prior to insecticide application. Fifty larvae were placed inside the boxes described in the preceding section. After the aerosol application was completed, the eggs remained in place for 2 h. This exposure period was selected based on the language of the insecticide label, which specified a 2-h exposure period. The overhead 100-watt incandescent lights inside the sheds were turned off after aerosol application so that the exposure conditions were in complete darkness. Temperature and RH were recorded using a HOBO data logger (Onset Computer Corporation, Bourne, MA, USA) placed next to treatment arenas. Temperature during the 2-h exposure period was 23 ± 1°C with 60% ± 8% RH for the first block and 21 ± 1°C with 60% ± 2% RH in the second block. After the 2-h exposure period, egg dishes and

larvae were collected from arenas and transported back to the laboratory. Of the 50 larvae exposed in the boxes, the number of escaped larvae ranged from 10 to 15 each time. Therefore the analysis was on the number of recovered larvae, not the original exposure of 50. Eggs were counted for each treatment and both eggs and larvae transferred to clean dishes with wheat diet and incubated at 27 ± 1°C and approximately 40% RH until adult emergence. This experiment ended when adults were considered unable to emerge in the insecticide treatments, which corresponded to the appearance of a second generation of larvae in the control dishes (approximately 1 week after adults began to emerge in the controls).

The experiment was designed as a split plot with the methoprene or untreated control as the whole plot treatment and the unobstructed and concealed positions as the sub-plot treatments. Data analysis was conducted using the Mixed Procedure (PROC Mixed) of the Statistical Analysis System (SAS) (SAS institute, 2001). Raw data were transformed by square-root analysis to stabilize variances. Means and standard errors for percent survival for each life stage were also calculated using the MEANS Procedure of SAS. Means for treatments were separated using the Waller-Duncan *k*-ratio *t*-test, with a significance level of $P = 0.05$ for each life stage.

Experiment 2

Upon conclusion of the first experiment, the false floors in the sheds were removed, the plastic was removed from the walls, and the sheds were reconstructed with new flooring and new plastic lining on the walls and roof. This was done to minimize the risk of contamination between experiments. In the second experiment, treatments consisted of methoprene, the pyrethroid esfenvalerate (Conquer®, McLaughlin Gormley King Company, Minneapolis, MN, USA), and a combination treatment of esfenvalerate with methoprene. The esfenvalerate solution, applied in proportion to the label rate of 29.6 mL diluted solution per 28.3 m^3, was made from a 296-mL concentrate in 3.8 L carrier oil. This chemical was applied in the same manner as described for the methoprene treatments (Exp. 1) and formulated as 15.5 mL esfenvalerate in 200 mL of oil for application. The delivery rate for esfenvalerate alone was similar to methoprene alone. This experiment was conducted in the same manner as Experiment 1; however, approximately 50 eggs of *P. interpunctella* were placed in painted 100-mL Petri dishes and set in the positions previously described. Following application of the treatments, 20 eggs were selected from each treatment and allowed to mature to adults. Six replicates were done at six different times, with only one replication of each life stage at each position. Four sheds were assigned the following chemical treatments: (i) carrier only; (ii) methoprene at the label rate; (iii) esfenvalerate at the label rate; and (iv) a combination of methoprene and esfenvalerate at their respective label rates. The fifth shed was designated as the untreated control. Temperatures within the sheds ranged from 21 to 27 ± 1°C with RH of 40%–60%. The temperature variation within the shed was due to the times of the day and the period of time over which the experiments were conducted. Any larvae that escaped the treatment arenas were disposed of and not included in the analysis. As described in Experiment 1, there was some escape of larvae, about 10–15 each time, therefore the statistical analysis was conducted as for Experiment 1 using the number of recovered larvae, not the original 50.

Experiment 3

Upon completion of the second experiments the sheds were de-constructed and reconstructed as previously described. In this experiment, different combinations of methoprene and esfenvalerate were assessed to determine if treatments at less than the label rate could be as effective as full rates. Four treatments were assigned to each shed: (i) full label rate methoprene plus one-third of the label rate esfenvalerate; (ii) full label rate methoprene plus two-thirds of the label rate esfenvalerate; (iii) full label rate esfenvalerate plus one-third of the label rate methoprene; and (iv) full label rate esfenvalerate plus two-thirds of the label rate of methoprene. The fifth shed served as the untreated control. The number of eggs and larvae were as described for Experiment 1. Treatments were assigned to each shed in a Latin square design blocked by day of treatment. Each of four replicate blocks was conducted at different times and on different days. The temperatures within the sheds ranged from 20°C to 27°C with RH of 45%–60%. The experimental design was a split plot and data were analyzed using the Mixed Procedure in SAS, as described for Experiments 1 and 2.

Partial budget analysis

While mortality is the measure of insecticide efficacy, cost is also a major consideration in an insect pest management program. Using chemical cost information calculated per 280 m^3, we conducted a partial budget analysis to compare costs of the methoprene and esfenvalerate treatments. Economic risk was calculated at three thresholds: 90%, 95%, and 99% mortality above which risk is

set equal to 0 (Tilley *et al.*, 2007). Equations used for this procedure are also described in detail in Tilley *et al.* (2007). The authors describe a modified Target MOTAD (mortality goal) model for optimizing cost and risk, but in the case of our three experiments, time and equipment cost are fixed and the only variable cost is the insecticides. Mortality is the inverse of adult emergence from exposed eggs and larvae, with target mortality and risk levels measured as deviations below a target mortality, above which risk is set equal to 0. Chemical and carrier oil costs were calculated based on current industry prices. Carrier oil costs fluctuate with the global petroleum market but for the purposes of this analysis were fixed at \$0.83/L or \$0.0008/mL.

Results

Experiment 1

There were no significant differences in adult emergence from eggs or larvae exposed to the methoprene aerosol in unobstructed versus concealed positions ($F = 1.3$, df = 1,16.6, $P = 0.27$). Therefore, data were pooled for further analysis. Emergence of adults from eggs exposed to methoprene was 10.8% ± 0.9% compared to 72.1% ± 9.9% in the control ($P < 0.01$), while adult emergence from exposed larvae was 7.1% ± 1.6% in the methoprene treatment and 87.7% ± 12.5% in the control ($P < 0.01$). Adult emergence from larvae exposed to methoprene was less than emergence from exposed eggs ($P < 0.05$).

Experiment 2

When *P. interpunctella* eggs were exposed to methoprene or esfenvalerate alone, or a combination of the two, there was again no significant difference in adult emergence with respect to unobstructed versus concealed positions ($F = 0.1$, df = 1,95, $P = 0.92$). Data were pooled as described for Experiment 1. Adult emergence from exposed eggs was significantly lower (~18%–30%) in the methoprene treatment than in the control (83.7% ± 5.8%) and the petroleum-based carrier (67.3% ± 32.4%) (Fig. 3). However, there was a slight carrier effect because adult emergence was lower than in the control. There was no difference in adult emergence between the methoprene and esfenvalerate treatments (both ~38%); but the combination reduced adult emergence to approximately half compared to either insecticide alone (Fig. 3).

There was a difference in larval response to the treatments; adult emergence from larvae exposed to methoprene alone was 0.4% ± 1.4%. However, adult emergence from larvae exposed to esfenvalerate was 90.4% ± 9.3%, which was not different from the control ($P = 0.71$) (Fig. 3). When methoprene was combined with esfenvalerate, adult emergence from exposed larvae was 2.0% ± 2.5% and similar to the methoprene treatment (0.4% ± 1.4%). The carrier did not reduce adult emergence from exposed larvae compared to the control (87.8% ± 10.1% and 89.5% ± 10.9%, respectively) (Fig. 3).

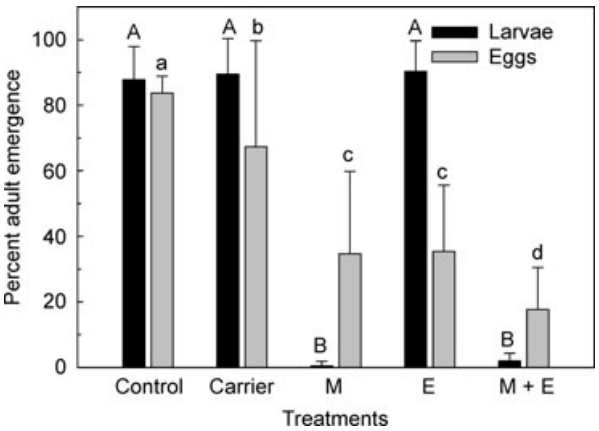

Fig. 3 Percent adult emergence (± SEM) from eggs and larvae of *P. interpunctella* exposed to aerosol applications of methoprene and esfenvalerate. Capital letters indicate differences between treatments for adult emergence from exposed larvae and lower case letters indicate differences between treatments for adult emergence from exposed eggs ($P < 0.05$). M = methoprene, E = esfenvalerate.

Experiment 3

All rates and combinations of methoprene and esfenvalerate resulted in reduced adult emergence from eggs and larvae of *P. interpunctella*, compared to the control ($F = 48.1$, df = 4,72, $P < 0.01$) (Fig. 4), with no differences in adult emergence when eggs or larvae were exposed in unobstructed versus concealed positions ($F = 3.6$, df = 1,4, $P = 0.13$). Data were pooled as described for Experiments 1 and 2. Larvae were more susceptible than eggs, based on the reduced adult emergence from exposed larvae ($F = 7.7$, df = 1,72, $P < 0.01$), and the interaction between eggs and larvae was also significant ($P = 0.03$). However, for each life stage, all combinations were equally effective at reducing adult emergence, with no differences between them ($P \geq 0.05$).

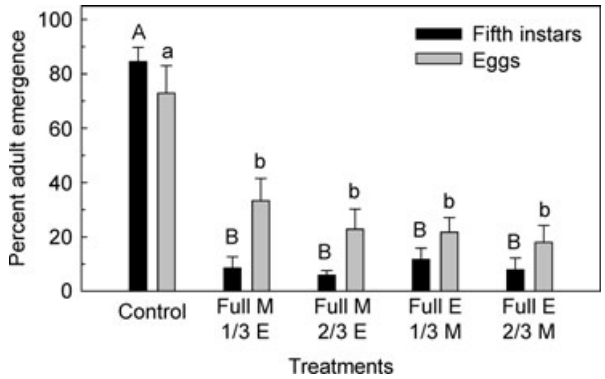

Fig. 4 Percent adult emergence (± SEM) from eggs and larvae of *P. interpunctella* exposed to aerosol combinations of methoprene and esfenvalerate treatments. Capital letters indicate differences between treatments for adult emergence from exposed larvae and lower case letters indicate differences between treatments for adult emergence from exposed eggs ($P < 0.05$). M = methoprene, E = esfenvalerate.

Partial budget analysis

The partial budget analysis for Experiment 1 shows the costs and risks associated with using methoprene to control *P. interpunctella* (Table 1). As mortality increases, risk levels decrease, as seen by the comparisons of the values between untreated controls and the methoprene treatment for both eggs and larvae. As the mortality levels increase from 90% to 95%, and then to 99%, the risk values in the table increase in response to those increased mortality levels. The cost of control is the same for both eggs and larvae.

Table 1 Summary of costs and risk levels for the methoprene exposures in Experiment 1 (adult emergence from exposed eggs and larvae).

Treatment	% mortality	90%	95%	99%	$ cost
C-eggs	27.9 A	0.62	0.67	0.87	0.00
M-eggs	89.1 B	0.04	0.07	0.10	0.70
C-larvae	12.3 a	0.78	0.79	0.83	0.00
M-larvae	92.9 b	0.03	0.05	0.07	0.70

Risk is presented as three thresholds: 90%, 95% and 99% mortality above which risk is set equal to 0. Capital letters denote significant differences for eggs, lower-case letters denote significant differences for larvae (Waller-Duncan *k*-ratio *t*-test, $P = 0.05$). Means for percent mortality of eggs and larvae (the inverse of emergence to the adult stage) are separated using statistical procedures described for Experiment 1. Costs are based on US dollars per 280 m^3. C = controls, M = methoprene.

Table 2 Summary of costs and risk levels for the methoprene and esfenvalterate exposures in Experiment 2 (adult emergence from exposed eggs and larvae).

Treatment	% mortality	90%	95%	99%	$ cost
C-eggs	16.3 D	0.62	0.67	0.83	0.00
O-eggs	32.7 C	0.59	0.63	0.66	0.25
M-eggs	65.3 B	0.26	0.30	0.34	0.70
E-eggs	64.6 B	0.26	0.31	0.34	0.71
M+E-eggs	82.2 A	0.10	0.13	0.14	1.17
C-larvae	12.2 b	0.78	0.83	0.87	0.00
O-larvae	9.3 b	0.79	0.84	0.88	0.25
M-larvae	99.6 a	0.00	0.00	0.00	0.70
E-larvae	9.7 b	0.80	0.85	0.89	0.71
M+E-larvae	98.1 a	0.00	0.00	0.01	1.17

Risk is presented as three thresholds: 90%, 95% and 99% mortality, above which risk is set equal to 0. Capital letters denote significant differences for eggs, lower-case letters denote significant differences for larvae (Waller-Duncan *k*-ratio *t*-test, $P < 0.05$). Costs are based on US dollars per 280 m^3. C = controls, O = oil carrier, M = methoprene, E = esfenvalerate, M + E = methoprene + esfenvalerate.

The methoprene, esfenvalerate, and oil carrier comparisons in Table 2 show that as the level of control for both eggs and larvae increases, the risk values within each category decrease, as described for Table 1. The combination treatment of methoprene + esfenvalerate represents the highest cost of \$1.17 per 280 m^3 but also the lowest risk. The bottom portion of Table 2 shows the cost comparisons for control of *P. interpunctella* larvae. Esfenvalerate alone is not particularly effective against the larvae even though it has a cost of \$0.71/280 m^3. Methoprene has the same cost but provides more control, based on the reduced adult emergence from exposed larvae. The combination treatment is the most optimal application based on the reduced adult emergence of eggs exposed to esfenvalerate compared to methoprene. All treatments containing methoprene resulted in decreased adult emergence of exposed larvae and were approximately equal in cost (Table 3).

Discussion

The aerosol applications of methoprene and esfenvalerate resulted in reduced adult emergence from eggs and 5th instar *P. interpunctella*. Based on our results, there was greater adult emergence from eggs exposed to the combination treatments in Experiment 3 (partial rates) than in Experiment 2 (full label rates). However, there were no

Table 3 Summary of costs and risk levels for the methoprene exposures in Experiment 3 (adult emergence from exposed eggs and larvae).

Treatment	% mortality	90%	95%	99%	$ cost
C-eggs	27.1 B	0.63	0.68	0.72	0.00
E + 2/3 M-eggs	82.0 A	0.12	0.14	0.17	1.01
E + 1/3 M-eggs	78.3 A	0.14	0.18	0.21	0.85
M + 2/3 E-eggs	77.2 A	0.15	0.19	0.22	1.00
M + 1/3 E-eggs	66.7 A	0.25	0.29	0.32	0.86
C-larvae	15.5 b	0.75	0.80	0.84	0.00
E + 2/3 M-larvae	92.1 a	0.04	0.05	0.07	1.01
E + 1/3 M-larvae	88.8 b	0.06	0.08	0.11	0.85
M + 2/3 E-larvae	94.2 a	0.01	0.03	0.05	1.00
M + 1/3 E-larvae	91.4 b	0.05	0.06	0.08	0.86

C = controls, combination. Risk is presented as three thresholds: 90%, 95% and 99% mortality, above which risk is set equal to 0. Capital letters denote significant differences for eggs, lowercase letters denote significant differences for larvae (Waller-Duncan *k*-ratio *t*-test, $P < 0.05$). Costs are based in US dollars per 280 m^3. Combination treatments were done using either the full label rate of esfenvalerate + either 2/3 or 1/3 the label rate for methoprene (E + 2/3 M and E + 1/3), or the full rate of methoprene + either 2/3 or 1/3 the full rate of esfenvalerte (M + 2/3 E and + 1/3 E).

treatments in Experiment 3 that contained the full rates of both methoprene and esfenvalerate, primarily because we were limited by the number of available sheds to use for the experiments. Using both insecticides in combination resulted in reduced adult emergence from exposed eggs and larvae, compared to adult emergence of eggs and larvae exposed to either insecticide alone.

Results from previous studies demonstrate the efficacy of aerosol insecticides (Arthur & Campbell, 2007; Arthur, 2008) for control of *Tribolium castaneum* Herbst, the red flour beetle. In the current study, the fact that we found no difference in adult emergence from eggs and larvae exposed in unobstructed and concealed positions for any treatment combination is also consistent with previous studies (Arthur & Campbell, 2007; Arthur, 2008) which indicate good distribution of the aerosol fog underneath equipment and pallets. Our current study also simulated a field condition whereby food products are stacked on pallets. Methoprene is an IGR that is a juvenile hormone analogue, and is an effective grain protectant (Chanbang *et al.*, 2007). It is also used to control for fire ants and mosquitoes (Aubuchon *et al.*, 2006; Henrick, 2007) and is stable over a wide range of temperatures.

Partial budget analysis determines levels of economic risk associated with control strategies (Boehlje & Eidman, 1984). A partial budget analysis can be used to compare different application methods and rates of methoprene alone and in combination with insecticides, such as esfenvalerate, so as to enable food production plant and warehouse managers to make more informed decisions. We standardized costs to 280 m^3 to develop a method to rapidly calculate costs for facilities based on size. In our analysis, equipment costs were fixed due to the unique needs and equipment requirements of different food manufacturing facilities. The exposure time of 2 h was consistent with label specifications, and would represent potential shut-down times for an active commercial facility. The cost of the oil carrier used in the aerosol formulations can be especially important because methoprene is applied at a much lower application rate than esfenvalaerate (thereby making the required amount of oil carrier higher); so that the approximate costs of the individual insecticides are approximately equal.

Given the concerns regarding safety of fumigants, the impending phase-out of methyl bromide and consumer preference for insecticides with little or no mammalian toxicity, using IGRs to control insect pests in grain mills and food warehouses could become more widespread. In addition, the larvae of *P. interpuctella* are difficult to kill with neurotoxic insecticides (Arthur, 1989, 1995, 1997). The combination of methoprene and esfenvalerate would seem to be a viable control strategy to control eggs and larvae of *P. interpunctella*.

Acknowledgments

This paper reports the results of research only. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture or by Kansas State University. The authors thank R. Cloyd for reviewing the paper prior to journal submission. This paper is Contribution Number 09–277-J of the Kansas Agricultural Experiment Station, Kansas State University, Manhattan, KS.

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Accepted June 9, 2009

